ENTERGY

Fossil Operations

1994 Technology Transfer Conference

FOSSIL OPERATIONS

Accesion For	
NTIS CRA&I	X
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution /	
Availability Codes	
Dist	Avail and / or Special
A-1	

Sheraton Baton Rouge Hotel
June 29-30, 1994

NEW ELECTRICAL CONTROL METHODS TO PREVENT POWER PLANT FOULING

Michael S. Mazzola,[a] Michael G. Grothaus,[b] Marianne Walch,[c] Joanne Jones-Meehan,[c] Mark S. Halpin,[a] Brenda J. Little,[d] and Joseph T. Johnson[e]

I. Introduction

Heat exchangers and other power plant related equipment represent critical operational and maintenance concerns. Scale formation and biofouling in power plant steam condenser tubes, in service water piping, and in process-liquid piping (manufacturing) are wide spread phenomena.[1] Biofouling and the resultant corrosion can be major factors in reducing the operating capacity of these systems. Since overrating these systems to account for the degradation in performance can be self-defeating, especially with heat exchangers,[2] there is a need for improved prevention technology. The choice of prevention technology is determined not only by economic factors such as maintenance costs and fuel efficiency, but also by environmental concerns related to the methods used to remediate the fouling. Chemical treatment, either for removal by acid treatment or for prevention by water chemistry control, is a typical remedy. Research into non-chemical methods for prevention of biofouling is justified by the costs associated with current methods and policies. As a result, a recent TVA-sponsored workshop[3] noted several emerging electrical technologies as candidates for the control of biofouling, including the zebra mussel, in both electric utility and ship board systems. These technologies can be separated into remediation methods (i.e., removal of existing fouling) and prevention methods.

One new remediation method utilizes pulsed acoustic waves at intensities above the cavitation threshold to remove accumulated scale and/or biofouling from the inside walls of piping and other enclosed structures. For example, we have demonstrated the removal of biofouling and scale from the inside of water-filled tubes by repetitively striking an arc at the end of a coaxial cable.[4] The pulsed acoustic wave successively removes accumulated deposits as the arc-discharge source is moved down the tube by an operator. This technique has the advantage of chemical removal, namely no physical contact with the tube walls, and the advantage of mechanical removal via scrapers, namely no chemical waste stream. Remediation of zebra mussel fouling with acoustic shock waves has been studied,[5] and while the method may be effective, questions of collateral damage to concrete structures from the scouring and disruptive effect of cavitation was a concern voiced by the power-plant operational community.[3]

---

[a] Dept. Electrical & Computer Engineering, P.O. Drawer EE, Mississippi State University, MS 39762

[b] Southwest Research Institute, P.O. Drawer 28510, San Antonio, TX 78228.

[c] Code R301, Dahlgren Division, Naval Surface Warfare Center, Silver Spring, MD 20903.

[d] Code 7333, Naval Research Laboratory, Stennis Space Center, MS 39529.

[e] Tennessee Valley Authority, 1101 Market St., Chattanooga, TN 37402.

An alternative we are studying is to use *low-energy* acoustic shock waves to prevent biofouling. We have completed a preliminary experiment at the Marine Corrosion Test Facility in Ft. Lauderdale, Florida in which acoustic shock waves were shown to reduce the growth rate of micro- and macrofouling in a sea water test loop. The prevention effect was observed upstream as well as downstream at ranges that excluded effects from cavitation and ultra-violet (UV) illumination. Since the test loop was made of clear plastic pipe and suffered no observable degradation due to exposure to the low-energy pulsed acoustic waves, we are optimistic that a prevention system prototype can be developed that avoids the concerns over collateral damage while producing a valuable prevention effect. As will be described below, the effect is based on physical mechanisms as opposed to chemical, and thus should have minimal environmental impact. However, a study extending this result to freshwater biofouling, and especially the zebra mussel problem, is still required.

II. Remediation with Pulsed Acoustic Waves

We begin this report by describing a measurement of pulse parameters from the shock wave launched by a fast underwater arc discharge, and the resulting removal of biofilms coating the interior of a 2.54-cm (1-in.) inside-diameter plastic pipes simulating heat exchanger tubes into which the shock wave was launched. This measurement was first reported in Ref. 4.

Our "baseline" experiment for evaluating the efficacy of a pulsed acoustic generator for remediating biofouling and scale consisted of a tank filled with deionized water to enhance repeatability. Residual biological activity was minimized by irradiating the water as it recirculated with UV radiation. The water resistivity was maintained between 7 and 9 MΩ-cm.

An underwater electrical discharge was formed in the tank by switching a capacitor into a roughly 2-m long coaxial cable (RG-213) via a triggered spark gap. The discharge current of the main energy storage capacitors was measured with a Pearson current transformer. The current waveform was a damped sinusoid with a period of 3.9 μs and a damping time of about three cycles. At a typical charge voltage of 12.5 kV, the peak current was 8.4 kA. The charging voltage ranged from 12 to 15 kV (32 to 50 J stored energy). The end of the RG-213 cable was neatly cut off to expose the cross section of the cable. When the capacitor is discharged into the cable, an arc forms across the cable insulator between the center conductor and the braid. This results in a fast, intense shock wave that propagates away from the cable tip. Rapid deterioration of the cable tip was observed after only a few shots, primarily an almost surgical removal of polyethylene followed by insulator punch through. Routine shaving of the cable end maintained a reasonably constant acoustic-shock intensity.

To detect the intensity and temporal nature of the shock wave, a stress-rate gauge was used. The Bauer PVDF stress-rate gauge is made from a ferroelectric material, and is capable of making nanosecond resolution measurements of high-intensity shock fronts. These gauges are calibrated at stresses ranging from 10 MPa to 10 GPa.[6] In the presence of an intense shock front, a current pulse is generated in the gauge and delivered to a 50 Ω terminated HP54111 digitizing oscilloscope. The current pulse can be integrated to yield the pressure difference across the shock front and an estimate for the shock front duration and spatial distribution. Based on the presence of cavitation within a few centimeters of the arc discharge, a stress of greater than 10 MPa (100 atm.) was expected. Measurements in free "space" were performed. The size of the water tank was sufficient that reverberation inside the tank could be ignored within the time window of the measurement (less than 100 μs). Shock wave parameters were directly measured with the PVDF gauge at a range of 6.5 cm and 13 cm. The shock wave was observed 47 μs and 96 μs respectively following inception of the arc discharge.

From these transit delays we estimated the speed of the shock wave to be about 1.3×10^5 cm/s, a value within 12% of the static speed of sound in water. A pressure differential of about 10 MPa was inferred from this measurement at 6.5 cm.

Biofouling removal experiments were performed by inserting the cable tip just inside 30-cm (12 in.) and 61-cm (24 in.) long, 2.54-cm (inside diameter) clear PVC pipes fouled with biofilms, grasses, and small crustaceans (1-3 mm diameter), and then initiating the electrical discharge to launch a shock wave down the tubes. Mud and silt also settled along with the biological material. This fouling resulted from immersion during the Spring months of 1993 in the waters of the Machodoc River, a tributary of the Potomac River bordering Dahlgren, Virginia. After as few as ten shots, virtually all of the biofilm, mud, and crustaceans were removed within the first 43 cm (17 in.) of the 61 cm (24 in.) PVC tube. Substantial scouring beyond the 43 cm range also occurred. Very short marine grass (less than 1 mm long) proved more resilient to the shock wave, even within a few centimeters of the arc discharge.

The pulsed acoustic wave described above can also be used to successively remove accumulated mineral deposits (scale) within interior piping (especially with bends, elbows, and valves), heat exchanger tubes, and steam condenser tubes as the arc-discharge source is moved down the tube by an operator. Flow Co. (Atlanta, Georgia), is an importer of a tube cleaning system apparently widely used throughout the Former Soviet Union (FSU). The Flow Co. device was tested in the Spring of 1993 on Unit Six of the coal-fired Wabash River Plant (Public Service of Indiana). While the *device* was found effective, the *service* was not economically viable because the system has serious design and technological deficiencies related to safety and maintenance that apparently are not issues in the FSU.

The suitability of using acoustic pulses generated by a properly designed system for tube cleaning is essentially an economic question. For example, the reported cost of cleaning the Wabash River Unit Six steam condenser (~9,000 32-ft. tubes) with formic acid was approximately $56,000, or 19.4¢/ft. Mechanical cleaning was not considered for this unit because the age of the condenser is such that unacceptable damage may be incurred in the tubes. The estimated cost per foot treated with the machine imported by Flow Co. from Kazakhstan was 22¢/ft. A cooperative effort between the Tennessee Valley Authority, the U. S. Navy, and Mississippi State University is being considered that could address and remove these deficiencies so that a fair judgement of the economic viability of the technique can be accessed. The target cost of the proposed TVA, Navy, MSU development program is less than 10¢/ft. The cost reduction is to be achieved by improving the lifetime of the applicator tip at the end of the coaxial cable and by improving operator control of the electrical power supply so as to dramatically improve operator productivity and safety. No hazardous waste would be generated by this cleaning method.

The payoff for nuclear plants may be even greater. For example, it cost approximately 35¢/ft.[7] to remove approximately 75% of the scale build-up in a Westinghouse CPS steam condenser at a large nuclear power plant.[8] In this particular plant, 80 tons of calcium carbonate scale was removed by mechanical means (multiple passes with air-driven scale cutters and scrapers) in six weeks during a 1992 scheduled outage for refueling.

III. Prevention with Pulsed Acoustic Waves

Sonics for biofouling control has been studied for many years.[9] Recently, conventional ultrasonic sources have been field tested for possible prevention of the freshwater zebra mussel (*Dreissena polymorpha*).[3] While these techniques are viewed by at least one major customer, the electric utilities, as still too experimental,[10] further research seems justified.[3]

Pulsed acoustic shock wave technology differs from conventional sonic/ultrasonic technologies in several important respects. First, the cavitation threshold is much higher for short-pulse, high-frequency (<1-μs duration, >1-MHz carrier) acoustic waves than for low-frequency (~10 kHz), continuous-wave (CW) ultrasonics: 10 MPa and 0.1 MPa respectively.[11] Second, the equipment used to produce an underwater pulsed shock wave is fundamentally different.

The pulsed acoustic technique applied to biofouling control accrues two advantages from the higher cavitation threshold. First, more acoustic power can be delivered to the water at higher efficiency, thus allowing larger areas to be treated at greater range. Second, in the case of conventional ultrasonics, the biofouling control mechanism has been correlated to cavitation,[3,12] which places the equipment and ancillary protective coatings at risk of short and long term damage due to the corrosive effect of cavitation. Based on data with pulsed acoustic waves to be described next, biofouling control from shock-wave treatment does not appear to be related to cavitation. Thus, a higher cavitation threshold allows a larger area to be treated at greater range while also reducing collateral damage.

In the area of equipment, high-power (tens of kilowatts) CW ultrasonic equipment tends to be sophisticated, particularly if swept frequency signals are required as suggested by some reports.[13] In contrast, the equipment required to produce pulsed acoustic shock waves uses underwater electrical-discharges formed by simple, relatively inexpensive arc-discharge equipment.

However, pulsed acoustics have received comparatively little study. One study, originally designed to demonstrate zebra mussel control, reported effective prevention of algae buildup in fresh-water piping over a range exceeding 15 m.[14] This range apparently eliminates a cavitation-related effect. Unfortunately, the lack of adequate control for this study and the poor statistical design made the interpretation of the results difficult. The zebra mussel data were inconclusive.

We have recently completed an independent study of biofouling control with pulsed acoustic waves in sea water. The acoustic pulse source consisted of a high-voltage power supply that produced an underwater electrical arc discharge. The repetition rate of the acoustic pulse was 0.5 Hz (once every two seconds). The experiment was conducted for the Naval Surface Warfare Center, Dahlgren Division at the Marine Corrosion Test Facility in Ft. Lauderdale, Florida (15 Feb.-27 Feb. 1994). The experiment demonstrated effective non-chemical biofouling prevention both upstream and downstream of the acoustic source. Specifically, this experiment demonstrated a significant reduction in the rate of micro and macro biofouling, with respect to an untreated control, in a sea water test loop treated with pulsed acoustic waves. Based on counts of plated cultures, at least an order-of-magnitude reduction in bacteria settling was observed at ranges of at least 10 feet for acoustic pulse treatments of less than 25 W average power (4 W/sq. ft. treated) for 10 hours each day. Direct observation of treated and untreated surfaces with an environmental scanning electron microscope (ESEM) revealed nearly complete prevention of bacterial and algae settling against significant fouling of the control. No degradation to the 2-inch-diameter, schedule-40 clear PVC plastic pipe was observed.

These effects occurred at ranges that exclude the influence of cavitation and ultraviolet illumination. The mechanism involves the interaction of the acoustic pulse with particles caught in boundary layers near the surface of all structures in contact with the flowing water column. This interaction reduces the effective "sticking coefficients" of the particles. The mechanism appears to be equally effective in preventing the accumulation of microscopic objects such as bacteria, algae, and larvae, as well as macroscopic objects such as sand. Since the effect is non-chemical, but confined to the range of the acoustic wave in the system being treated, it should be more environmentally compatible than competing chemical biocides and thermal treatments alone. Alternatively, experience with other techniques that influence boundary layer diffusion[15] makes it likely that biocides used in conjunction with pulsed acoustic treatment will be more effective, especially in low-flow stagnation regions. Since the focus is on prevention of settling at the microfouling level (including larvae-born invasions such as the zebra mussel) a collateral waste stream is all but avoided.

IV. Prevention with Electric Fields and Currents

The use of electric fields and currents in biofouling control applications has met with varied results. Generally speaking, the methods show variable results that have proven difficult to duplicate. The use of electric fields to control biofouling requires the creation of a capacitive device that uses water as the electrolyte. Depending on the specific chemical content of the water, the leakage currents through such a device can become sufficient to produce electro-chemical reactions. A device with low leakage current can produce electric fields of sufficient magnitude to prevent biofouling.[9] A large-leakage current can also be applied in biofouling control applications, but additional research is required to determine exactly what the active agent is (electrical, chemical, or some other effect).[9,15]

The use of electric field theory to develop a "killing area" for zebra mussel larvae has been chiefly developed in the United Kingdom. The concept uses a pulsed electric field (400-1000 Hz) to induce fatal currents into the zebra mussel larvae.[16,17] The difficulties with this method are associated with the potential effects on other species. At this time, work has not been done to determine mortality rates for zebra mussel larvae relative to other larvae (fish, for example). Additional work has revealed that exposure to electric field intensities of 0.04 V/m has been reported to produce "instant" disorientation in mussel larvae.[3] The disorientation is caused by muscular contractions and is of sufficient duration to allow the larvae to pass through the plant without attaching. Electric fields that are of lesser magnitude can be effective, but the exposure time required for both adult mussels and larvae increases rapidly. For example, one report states that 120 hours of exposure is required to produce "significant" mortality rates in adult zebra mussels for field strengths of 0.03 V/m.[3]

Electro-chemical reactions can be started using relatively low currents and low field intensities. One immediate result is electrolysis of the water to produce chemical concentrations that are lethal to the fouling organisms. A more advanced process is termed cathodic protection and may be applied with or without a chemical coating of the material to be protected. One example of a chemical pre-treatment involves application of a thin coating of inorganic zinc silicate which forms a lethal layer (to mussel larvae) of Zn^{++} ions. Water contamination (with Zn) is not a problem.[3] Reports indicate that current densities as low as 50-75 mA/square foot can prevent biofouling, but more work is required to determine the required coating material and the exact nature of the required current densities. Additional reports indicate that the exposure of the boundary layer of piping, etc., to low dc currents dramatically impacts the effects of many commonly used biocides.[15] As with the application of electric fields, however, the effectiveness of electric currents is strongly dependent on the water chemistry.[3]

V. Conclusions

While the scouring experiment demonstrated that remediation of biofouling with arc-generated shock waves is possible, the experiment also indicated that the effect is essentially local. The sea water biofouling prevention experiment demonstrated that pulsed acoustic waves can prevent biofouling over considerably greater ranges than they can remove biofouling (hundreds instead of tens of centimeters). This is because biofouling prevention with pulsed acoustic waves appears to be possible at lower shock-wave intensities; specifically, at intensites below the cavitation threshold. Here high-voltage pulsed techniques may offer a significant advantage over conventional continuous-wave (CW) ultrasound because the higher cavitation threshold for short acoustic pulses allows higher peak intensities to be delivered to the water before encountering non-linear loss mechanisms which severely limit range. In addition, it is highly desirable to avoid long-term exposure of metal and concrete surfaces to intense cavitation because of the corrosion associated with cavitation. However, short-term exposure, such as during cleaning of mineral deposits from steam condenser tubes, probably poses little threat compared to the tube-wall damage caused by mechanical scraping or the tube-wall thinning caused by acid treatment. Further work will be required to verify this assumption. Additional follow-on work is required to quantify a freshwater biofouling prevention effect, especially on the zebra mussel. This can be accomplished by conducting a field experiment similar to that performed in sea water at the Marine Corrosion Test Facility.

Direct application of electric fields and currents for biofouling prevention is another possibility. Technology based on electrochemistry at surfaces is relatively advanced and has prior acceptance for corrosion control. However, cost and the potential for continuous release of heavy metals or other chemical toxins restrains this technology. The electric field "stun" or "kill" approaches have potential application in the long term, but the available evidence indicates a need for more study to establish reliable effects that can be developed for practical use.

References

1. Carl H. Fromm and Srinivas Budaraju, "Reducing equipment-cleaning wastes," *Chemical Engineering*, vol. 95, pp. 117-122, July 1988.

2. J. G. Knudsen, "Fouling of heat exchangers: Are we solving the problem?," *Chem. Eng. Prog.*, vol. 62(7), pp. 63-69, Feb. 1984.

3. Stephen Levy, "Final Report on Electrical Methods for the Control of Zebra Mussels," EPRI Power Electronics Applications Center, Knoxville, TN, May 1993.

4. M. G. Grothaus, M. S. Mazzola, M. Walch, and J. Jones-Meehan, "Pulsed power remediation and prevention of biofouling," Presented to 9th Inter. Pulsed Power Conf., Albuquerque, New Mexico, June 1993.

5. J. R. Duncan, M. Rader, S. Levy, I. Alexeff, J. A. Drake, J. Johnson, "The use of pulse power to control zebra mussels," Presented to 3rd Inter. Zebra Mussel Conf., Toronto, Ontario, Canada, Feb. 1993.

6. D. E. Wackerbarth, M. U. Anderson, R. A. Graham, *PVDFSTRESS: A PC-Based Computer Program to Reduce Bauer PVDF Stress-Rate Gauge Data,* Sandia National Laboratories Technical Report SAND92-0046, 1992.

7. John L. Tsou, program manager for the Electric Power Research Institute's Plant Performance Program, private communication, May 1993.

8. R. David Thurston and Ronald L. Stiemsma, "Clinton Power Station Condenser Performance Evaluation and Improvement Program," Illinois Power Company Report.

9. J. M. Jones and B. Little, "USS PRINCETON (CG 59): Microbiologically influenced corrosion (MIC) and macrofouling status of sea water piping systems," Naval Surface Warfare Center Technical Report 90-176, June 1990.

10. T. J. Maiman, "Utility perspective," *Proc. Electric Utility Zebra Mussel Control Technology Conf.*, EPRI Technical Report 100434, pp. KA-19 to KA-20, 1992.

11. R. J. Urick, *Principles of Underwater Sound*, McGraw-Hill, New York, pp. 78-79, 1983.

12. Dennis T. Burton, Leonard B. Richardson, and Robert J. Taylor, "Control of Colonial Hydroid Macrofouling by Free-Field Ultrasonic Radiation," *Science*, vol. 223, pp. 1410-11, 1984.

13. E. C. Fischer and V. J. Castelli, "Technology for control of marine biofouling--a review," *Marine Biodeterioration: An Interdisciplinary Study*, Naval Institute Press, Annapolis, MD, p. 261, 1981.

14. A. Bryden, "New application of an acoustic device," Presented to 3rd Inter. Zebra Mussel Conf., Toronto, Ontario, Canada, Feb. 1993.

15. B. Costerton, "Control of Microbial Biofilm by Electrically Enhanced Biocide Treatment," *Proc. 12th Inter. Corrosion Congress*, vol. 5B, pp. 3803-06, 1993.

16. U.S. Patent No. 4,943,654, July 24, 1990.

17. Morse, et al., "Induced GABA Production by an Electric Field," Marine Science Institute and Department of Biological Science, University of California, Santa Barbara.

REPORT DOCUMENTATION PAGE

Form Approved
OBM No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	June 1994	Proceedings

4. TITLE AND SUBTITLE

New Electrical Control Methods to Prevent Power Plant Fouling

5. FUNDING NUMBERS

Job Order No.	13332A
Program Element No.	0601153N
Project No.	03103
Task No.	320
Accession No.	DN094463

6. AUTHOR(S)

Michael S. Mazzola,[a] Michael G. Grothaus,[b] Marianne Walch,[c] Joanne Jones-Meehan,[c] Mark S. Halpin,[a] Brenda J. Little,[d] and Joseph T. Johnson[e]

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Research Laboratory
Oceanography Division
Stennis Space Center, MS 39529-5004

8. PERFORMING ORGANIZATION REPORT NUMBER

NRL/PP/7333--93-0027

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Naval Research Laboratory
Systems, Support, and Requirements
Stennis Space Center, MS 39529-5004

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

1994 Technology Transfer Conference, Fossil Operations
June 29-30, 1994, Baton Rouge, LA

[a]Mississippi State University, MS 39762
[b]Southwest Research Inst. San Antonio, TX 78228
[c]Naval Surface Weapons Center, Silver Spring, MD 20903
[d]Naval Research Laboratory, Stennis Space Center, MS 39529
[e]Tennessee Valley Authority, Chattanooga, TN 37402

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Heat exchangers and other power plant related equipment represent critical operational and maintenance concerns. Scale formation and biofouling in power plant steam condenser tubes, in service water piping, and in process-liquid piping (manufacturing) are wide spread phenomena.[1] Biofouling and the resultant corrosion can be major factors in reducing the operating capacity of these systems. Since overrating these systems to account for the degradation in performance can be self-defeating, especially with heat exchangers,[2] there is a need for improved prevention technology. The choice of prevention technology is detemined not only by economic factors such as maintenance costs and fuel efficiency, but also by environmental concerns related to the methods used to remediate the fouling. Chemical treatment, either for removal by acid treatment or for prevention by water chemistry control, is a typical remedy. Research into non-chemical methods for prevention of biofouling is justified by the costs associated with current methods and policies. As a result, a recent TVA-sponsored workshop[3] noted several emerging electrical technologies as candidates for the control of biofouling, including the zebra mussel, in both electric utility and ship board systems. These technologies can be separated into remediation methods (i.e., removal of existing fouling) and prevention methods.

14. SUBJECT TERMS

corrosion; biofouling; power plant

15. NUMBER OF PAGES

9

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102